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An inquiry-oriented approach for making the best use of ICT in the classroom

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Summary

Many decades after the introduction of ICTs into science classrooms, there are still many unanswered questions about the impact technology has in students' learning. This article addresses the general question: "What ICTs are the most useful, and how can they contribute to better learning in the science classroom?" We conceive **ICTs as tools that can enhance particular learning situations or environments, and in this sense, this article elaborates on the most appropriate technologies for particular learning environments and discusses in what order, and with what purpose, these technologies should be used.**

The first part of this article highlights the most commonly used technologies in science classrooms, reviewing the unique opportunities they offer that would not be possible otherwise. After discussing the potential (or lack thereof) of these technologies, the second part of the article presents a proposal for using some of them in a specific pedagogical context: an inquiry-based learning cycle for laboratory work. The main aim of the proposal presented here is to discuss how a certain teaching and learning approach, such as inquiry-based learning, and a certain teaching and learning situation, such as school laboratory work, can be enriched by the use of ICTs. Finally, **a detailed** example of how specific ICTs are used in laboratory work sessions with an inquiry approach is also explained. This practical case comes from a research-based activity sequence on kinematics and dynamics developed for secondary school students within the framework of the local project REVIR.

Keywords: learning, research, secondary school, Information and Communication Technologies (ICT), laboratory work, inquiry approach

Introduction

The information society in which we are immersed requires or imposes the use of technologies in all ambits. These technologies have changed and continue changing our everyday lives as regards communication among individuals, and the use, development and processing of information. The school cannot be removed from this reality. On the contrary, it should look for the means to attain the maximum benefit from such technologies for students' learning. OCDE (2001) already highlighted three main reasons to include Information and Communication technologies (ICTs) in education: economic, social and pedagogical. The pedagogical arguments, focused on the role of ICTs for teaching and learning processes, have become more influential as the designed applications have become more usable and useful to facilitate students' learning in formal and informal contexts, making lifelong learning possible.

As Cox and Marshall (2007) state, many decades after the introduction of ICTs into classrooms there are still unanswered questions about the impact of technology in students' learning, and how it has affected simple and complex learning tasks. The answers to all these questions are important for informing educational policies, for designing teacher education programmes, and for reforming classroom implementation. A broad variety of questions and reflections on the effects of ICTs in education have been approached by multiple research studies. Many of these previous studies have been considered vague as to their results and implications. For instance, some of them have analyzed the potential of ICTs for promoting students' learning independently of the topic or subject dealt with and so, they have suggested general principles or guidelines on how to integrate and use ICTs. We strongly believe in the need of taking into account research results of relevant educational research, but also extending and enriching them at the level of didactics of the particular disciplines and specific teaching and learning approaches.

In the science education field, ICTs have proven to be useful tools that can contribute to these purposes, despite interesting critical views. ICTs as teaching resources are not considered a benefit in themselves (Osborne & Hennessy, 2003). According to Jonassen (2006), students do not learn from ICTs but from thinking (with or without ICTs). It has also been found that teachers and their pedagogical approaches are considered crucial elements that can establish significant differences. The study carried out by BECTA, for instance, evidenced a strong correlation between ways of using ICTs and students' attainment (Cox & Abbott, 2004). Therefore, it is necessary to analyze adequate forms of incorporating and using ICTs properly and fruitfully. For this reason, this article elaborates on the benefits of and recommended teaching approaches for the teaching and learning science using ICTs. The sort of questions we would like to contribute to with our proposal are:

- What and how should ICTs be used so that they contribute to better learning in the science classroom? In particular:
  - How can a certain teaching and learning approach, such as inquiry-based learning, be enriched by the use of ICTs in the science classroom?
  - How can a certain teaching and learning situation, such as school laboratory work, be enriched by the use of ICTs in the science classroom?

Which opportunities offered by the use of ICTs are not otherwise possible?

ICTs provide teachers with a wide range of different tools to be used in their classes. Nowadays, everybody assumes that the introduction of such technologies per se does not transform science education. Rather, as mentioned before, it is acknowledged the critical role played by the teacher in: creating the conditions for ICT-supported learning through selecting; evaluating appropriate technological resources and designing, structuring and sequencing a set of learning activities. Often teachers use ICTs as a support or complement for their lessons in a way that replicates common classroom practices, rather than using them as a tool which allows redesigning contents, aims, activities and the pedagogical approach itself (Hennessy et al., 2003). Not surprisingly, Moseley et al. (1999) find out that teachers choose certain ICTs, design certain activities in which these ICTs are used and decide their teaching strategies according to their own perspectives on teaching and learning.

It is generally agreed that educational ICTs should be selected depending on their potential and relevance for teaching and learning a certain topic, instead of depending on their visual attractiveness. For this reason, the appraisal and selection of educational technological resources should start from the analysis of and reflection on the underlying conception of learning that each tool is intended to promote (Pintó, 2009). Depending on this conception, some technologies can be considered right from the start appropriate or non appropriate for educational purposes. Let us highlight some of the possibilities attributed to the most commonly used tools which have been conceived and designed to support the process of teaching and learning science. Our aim here is to present the potential (or lack of potential) of them before proposing a particular way to use them in a particular teaching and learning approach and context.

1. Software that allows teachers to design interactive tasks

Using these applications, which are non specific of science, teachers can create different types of tasks and exercises: multiple-choice, “fill-in-the-gaps”, crosswords, matching questions and answers, ordering sequential actions, etc. The main aim of these exercises is that students associate a correct answer to a certain question. Nevertheless, being able of associating correct answers to questions does not imply having understood deeply some concepts or models, in the same way that using correct definitions of a concept does not imply having understood or learnt it. For this reason, we do not consider these tools as a resource that promotes deep learning but rote learning.

2. Software to represent and organize knowledge

Although this kind of software has not been specifically designed to teach and learn science, it has been included in this section because of the pedagogical potential attributed to them. The applications intended to facilitate students’ organization and representation of their knowledge in a graphical and structured way are considered useful tools to support their understanding and learning. Such applications can help students to be aware of the structure of their own knowledge, allowing them to establish relationships between different pieces of information. This purpose can be attributed to technological tools that facilitate the elaboration of concept maps, mind maps and V diagrams of Gowin, among others.

3. Software to visualize systems and phenomena (computer animations)

There are numerous applications that allow visualizing dynamic images of systems or processes and exploring virtual representations of the physical world. The so-called computer animations consist of tools that allow users to visualize but not interact with these representations or models that are behind the images. Therefore, users cannot try modifying certain conditions or parameters with the purpose of analyzing how these variables affect the phenomenon which is visualized. On the contrary, the sequence of observable events is predetermined by the designer, who has previously decided the models or ideas that want to make explicit according to his/her intended purposes, and users can only observe and try to interpret these models. Several research studies (Kress & van Leeuwen, 1996; Halkia & Theodoridis, 2002; Pintó & Ametller, 2002) have evidenced that images are not as “transparent” as are expected and understanding their meaning relies on a series of subtle and complex processes. Although observing dynamic images in the computer screen can be motivating or illuminating for many students, it does not guarantee their understanding and so, visualization of the phenomena incorporated in a computer animation does not imply that students elaborate or apply an appropriate explanation or conceptual model. In any case, it is one’s own previous knowledge that orients or guides the observation (Glynn & Duit, 1995).

4. Software to visualize and interact with systems and phenomena (computer simulations, virtual laboratories)

These applications allow visualizing processes or systems and, moreover, user interaction with them. Computer simulations and virtual laboratories allow representing certain systems or contexts in which experimental procedures or phenomena take place, using specific languages (graphic, text, algebraic, diagrams, etc). The interactive, dynamic and multimodal nature of this kind of applications can facilitate students’ analysis of the influence of certain factors in the process that is observed. These tools have the potential of providing access to experiences not otherwise feasible because of their complexity, cost or danger. However, these virtual experiments tend to delete any irregularity from graphs, and experimental conditions are always ideal and stable. These idealizations should be contrasted with real experiments to avoid misleading views or oversimplifications on how experiments are carried out in real setups.

The behaviour of the objects or systems that can be observed in computer simulations is based on theoretical models, previously introduced by the designer. The reason why computer simulations are considered tools that mediate and facilitate the relationship between reality and models or theories is the possibility of interaction between students' mental models on a certain topic and the underlying conceptual models in the simulation (Monaghan & Clement, 1999; Pintó & Gutiérrez, 2004; Evagorou et al., 2009).

In order to use computer simulations efficiently, it is essential to guarantee that students understand the meaning of the elements represented and have certain knowledge on the scientific topic that is tackled. Moreover, students' experimentation with a computer simulation should be supported by a sequence of tasks that orient students in their work and promote students' reflection during the manipulation of the simulation. Computer simulations can lead students to ask "What if…?" questions. This means that these resources are useful to engage students in scientific inquiry tasks. Identifying and controlling variables that affect a certain phenomenon is considered an important scientific procedure and the interaction between students and computer simulations can promote students' development of this procedural knowledge. However, as mentioned, they are not real experimental settings where real data is dealt with: despite inquiry can be triggered by simulations, an inquiry would be epistemologically compromised if done using simulations alone.

5. Computational modelling tools

Nowadays, teaching of models and modelling has become a recurrent subject in science education research, pointing to the fact that a better understanding of functions, features and status of conceptual models is linked with a meaningful learning of science (Gilbert & Boulter, 1998). Undoubtedly, an important task for a scientist consists of elaborating appropriate and plausible explanations to account for phenomena or processes that have been previously observed or experienced, building or applying conceptual models (Clement, 2000). These models are considered more or less powerful depending on their explicative and predictive nature.

According to Lijnse (2006), the present focus on modelling is largely due to three main reasons: (i) the recent constructivist attention to conceptions that students bring to the classroom, which is interpreted as an example of the fact that people experience the world in terms of their mental models and modelling; (ii) the present emphasis on the role of philosophy in science education, which has resulted in stressing the importance of attention for the nature of scientific knowledge and of scientific models in particular; (iii) the present availability of computers that has greatly enhanced the possibilities for creating and testing numerical models, both in science and in science education.

Computer modelling applications have progressed with the purpose of making the building of models more accessible to students, allowing the proliferation of interesting applications. Research studies on the use of computational tools for modelling processes in science education have given positive results in terms of students' meaningful learning (Feurzeig & Roberts, 1999; Penner, 2000; Lawrence, 2002). These applications have been designed to facilitate students' building of models based on their own conceptions about how the world works. These tools promote students' reasoning in terms of variables that affect a certain phenomenon and qualitative or quantitative relationships between these variables. Moreover, computer modelling tools allow running the models (introduced in form of equations or icons) that have been built so that students can visualize the subsequent result and compare it with the behaviour of the reference system from real world.

Comparing computational modelling tools to computer simulations, one realizes that the main difference lies in the possibility of running one's own models or a model introduced by the designer. Students using a modelling tool need to analyze the components of a system, the relationships between these components, and they also need to know the (textual, graphic or algebraic) language of the software to express their own conceptual models. In contrast, using a computer simulation requires decoding images and relating their dynamism to scientific laws, principles or models. For this reason, the cognitive demand required for using computer modelling tools is considerably higher than the cognitive demand necessary for using computer simulations: a deep understanding of the phenomena and capacity to abstract from it to the theoretical level is necessary.

6. VBL (Video-Based Laboratory)

Video-based laboratory software basically consists of a tool to analyze motion using video data. More specifically, these applications allow replaying on a computer screen videos of motions that have been previously recorded, and select the position of an object along the motion. Due to the fact that the video has its own timeframe, and using some object of the video to measure its size and to define the scale of distance, the software is able to convert the position of an object in position-time data. This allows showing the video of the phenomena and simultaneously creating a graph of position, speed or acceleration as a function of time. VBL provides students with a tool that can help in the study of pre-recorded real-world or artificially produced events. This kind of software is considered a powerful tool for improving students' understanding of physics graphs (Beichner & Abbott, 1999).

7. Data-logging systems and MBL (Microcomputer-Based Laboratory)

These systems consist of sensors that can be connected to computers by means of external or internal interfaces, which are the devices responsible for converting analogical signals into digital signals. These technologies are suitable tools for laboratory work since they allow collecting data of the evolution of a certain signal and representing these data in graphs or numerical tables in a computer screen by means of specific software while the phenomenon under study is taking place. Nowadays, there is a broad variety of sensors that can be used within these systems and they measure accurate data of temperature, force, pressure, position, magnetic field, sound intensity level, pH, etc. The characteristics of these technological equipments allow measuring both quick phenomena (e.g. free fall of a ball) and very slow phenomena (e.g. thermal equilibrium). Furthermore, the corresponding software not only makes possible different types of representation of the collected data (graphs and numerical tables) but also provides students with tools to analyze these data (e.g. data selection, change of scale in the graphs, adjustment of mathematical functions to the empirical data, etc).

The use of this technology can enhance a more profitable use of time during laboratory work, releasing students from laborious manual or mathematical processes and allowing the possibility of using more time for thinking and analysing the observed phenomena, getting involved in scientific discussion (student-student, student-teacher) and interpretation (Pintó et al., 1999; Finlayson & Rogers, 2003). Moreover, the fact that the visual feedback in the computer screen is immediate supports students' exploration and interpretation and facilitates students' establishment of relationships and distinction between real-time events, measured variables and theoretical models during the laboratory work situation (Brasell, 1987; Beichner, 1990).

The potential of these technologies has been the focus of multiple research studies during the last three decades. These tools have been evidenced as adequate technological resources to improve students' procedural skills, such as graphs interpretation (McDermott et al., 1987; Mokros & Tinker, 1987; Sassi et al., 2005), to promote students' reasoning skills (Friedler et al., 1990) and conceptual understanding (Thornton & Sokoloff, 1990; Fernández et al., 1996, Saez et al., 2005).

How can ICTs be used within an inquiry approach for science laboratory work?

According to the aforementioned, all ICTs that are common in science classrooms are not equivalent regarding the sort of learning experience they can provide to students. As a consequence, it is not only important that teachers introduce ICTs in their teaching but that they use the more suitable ICTs from the point of view of a constructivist approach and according to the particular learning intended with the activities undertaken. In this sense, ICTs should be envisaged as tools to be used to create a particular learning situation or environment, and in this sense, it is important to reflect on what are the most interesting tools for particular learning environments and in what sequence and with what purpose should these tools be used.

Inquiry-based learning as a useful pedagogical approach for science education

In the case of science education, there is a certain consensus and also some evidence that inquiry as a pedagogical approach is a motivating, meaningful and pedagogically rich scenario for the learning of science (NRC, 2000; Rocard et al., 2007; Osborne & Dillon, 2008). There are very different rationales and views behind the term "inquiry oriented teaching". However, it is generally agreed that the aim of inquiry in the classroom is to engage students in questioning and investigating for learning both scientific content knowledge and knowledge about the processes of science. Despite discussions about the lack of epistemological authenticity of many classroom inquiry activities (Chinn & Malhotra, 2002), it is also generally agreed that an inquiry-oriented approach aims to bring authenticity to the traditional science classroom by involving students in reasoning and investigative tasks that resemble those of scientists. In addition, inquiry as a teaching and learning approach is related often with constructivist ideas, thus involving student-centred projects, students' active involvement and crucial teacher guidance (Schwartz, Lederman & Crawford 2004).

As a pedagogical approach, inquiry is usually triggered through good driving questions or problems to be solved, quite often in richly contextualised scenarios. It generally involves practical work, despite its focus goes beyond the acquisition of laboratory skills (such as measuring, reading graphs, etc.) to address more significant scientific competences (such as using of evidence, using models, predicting, etc). All these skills and competences are necessary to productively engage in the questioning, thinking, planning, reflecting, interacting, arguing, etc. that takes place when engaging in a scientific investigation. In this sense, a science lesson or sequence of activities within an inquiry orientation has special characteristics as a particular learning environment. As a consequence, it is interesting to think of which ICT tools are the most interesting ones to be used within this pedagogical approach, in what activity sequence and with what objectives.

A proposal for school laboratory work within an inquiry-oriented approach using ICTs

From our point of view, the most interesting ICT tools for those inquiry activities that explicitly include laboratory work are: computer simulation and modelling tools, data-logging and video analysis tools, and tools for representing and organising knowledge. A possible sequence for the use of these tools is shown in Figure 1. Our proposal for a basic inquiry cycle for laboratory work in science education, including ways of using these ICT tools to enhance the learning potential of this cycle, is explained below. The aim for including these ICT tools is not only for a better learning of science contents and skills involved, but also for greater achievement of digital competence and a more sophisticated idea of how real science is done in ICT-enhanced laboratories.

Figure 1 represents a basic inquiry cycle for laboratory work in the science classroom. As mentioned, this inquiry cycle is initiated by the formulation, identification or understanding of a contextualised question or problem to be solved. Once the need for empirical observation/results is established, students' prediction needs to take place. This prediction phase has been largely discussed in science education as a crucial moment for any experimental work intending meaningful learning, due to the fact that it allows students to explicit their reasoning and getting to a predicted result, for later comparing it with the empirical result. Within an inquiry-oriented framework, however, the laboratory activity goes beyond a basic POE structure (prediction, observation, explanation, White & Gunstone, 1992) to include situations of different levels of inquiry, in which the experimental design can be done by students themselves or not, in a more or less guided way depending on its complexity and the familiarity of students with the equipment and measurement procedures. The next important phase to take place in a cycle of laboratory work refers to the collection of empirical data and its analysis and representation. Results obtained are generally compared with what was predicted and, in the relevant cases, to the theoretical model or piece of scientific knowledge intended to be constructed and learnt along the inquiry cycle. However, the comparison and connection of results obtained empirically with the expected results and, even more complex, also with the intended scientific knowledge is not at all easy for students and will not happen spontaneously during the laboratory work. Teachers need to provide explicit opportunities so that this construction of new knowledge takes place. In this sense, teachers' guidance is essential to help students restructure what they thought (their initial models) in the view of the new results and the scientific models that accommodate with them. Even though the scientific model is not derived from the laboratory work results, the scientific model (or some aspects of it) can make more sense to students in the view of these empirical results. Due to the fact that the interest of an inquiry cycle, whether in the laboratory or not, is not only learning procedural knowledge and global inquiry skills but also intended scientific knowledge, we claim the need for connecting empirical results with the theoretical dimension at this moment of the learning cycle, restructuring and synthesising the knowledge being used and constructed in this situation. Finally, in order to promote meaningful learning of any piece of knowledge, it is necessary to include possibilities of transfer to extended or new contexts and situations. In this sense, the final phase of our inquiry cycle is the generalization and application of conclusions (from the analysis of results) or new knowledge obtained to new contexts and situations. This application or transfer phase can elicit new doubts which, in turn, can initiate a new inquiry cycle.

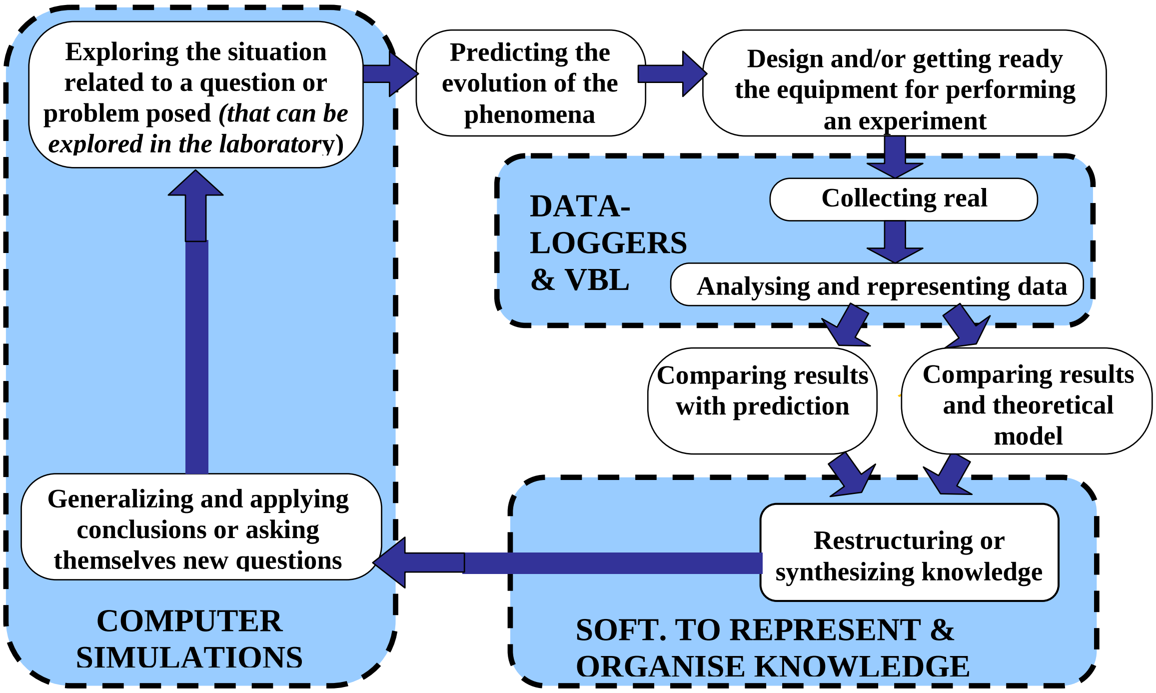

Figure 1: Phases of a learning cycle for school laboratory work within an inquiry-oriented approach using ICTs for teaching and learning

The inquiry cycle of Figure 1, as described previously, does not necessarily need for ICTs to be used. It is a general, basic cycle to guide laboratory work with or without traditional equipment. However, the learning potential of this situation can be enhanced by including particular ICT's in particular phases, becoming an inquiry cycle for ICT-enhanced laboratory work in the science classroom. As shown in Figure 1 (see blue areas), we propose that three types of ICT tools (computer simulation and modelling tools, data-logging and video analysis tools, and tools for representing and organising knowledge) should be used in three different phases of the general labwork inquiry cycle: initial and final exploration; data gathering, analysis and representation, and restructuring and synthesising of new knowledge.

The initial exploration phase and the transfer or application phase can benefit from the enormous possibilities of computer simulations. For instance, computer simulations can offer a contextualised initiation of inquiry, by allowing students to explore qualitatively situations and phenomena difficult to be reproduced in the science classroom. An example would be a simulation about the noise heard inside and outside a disco depending on the materials used to isolate it acoustically. In a similar way, a simulation can be very interesting to transfer knowledge to new situations, allowing much more diversity than the one possible in the real experimental work. For instance, continuing with the previous example, a simulation could allow students to choose among different materials (sound reflectors and absorbers), put them in different parts of a building and simulate their acoustic behaviour. The fact that the test done within the simulation environment is proposed, according to the cycle of Figure 1, after undertaking a real experiment is purposeful to help students see this activity as one of a different nature than the empirical one done by themselves: it is not an experiment. In addition, the work with the simulation is also proposed to be done after connections with the theoretical model in order to facilitate students' understanding of the difference between a theory (if available) and a set of numerical data like the one obtained by running the simulation.

From our point of view, this particular use of simulations within an inquiry cycle serves to several objectives. First, it takes full advantage of the enormous potential of simulations to "play" with simulated reality either for triggering initial thinking about the phenomena (which, even if familiar, does not necessary has to be well-known) or for transferring what have just been learnt to new situations. Second, it minimises the problematic epistemological misinterpretation of simulations and virtual laboratories by students and sometimes teachers as pseudo-real contexts for empirical work, where it seems possible to obtain results and data. In this sense, we make a strong claim here for simulations and virtual laboratories to be used to complement, never substitute, real laboratory work. We will elaborate further on this point in the following paragraphs, when discussing the next phase of the inquiry cycle proposed here.

In traditional school laboratory work, the collection of empirical data and its analysis and representation are two separated and distanced activities, both in time and sometimes even in space. While data is gathered during the laboratory work session, its representation and analysis is generally done after it, by producing graphs and doing mathematical operations with the gathered data outside the experimental setting. In both cases, it is mostly the learning of procedural knowledge what is addressed in these activities. However, once data is represented and analysed, a linkage between the observed and empirically researched phenomena and the results obtained are expected to be done by students, aiming for conceptual knowledge to take place. Unfortunately, this is not generally the case, as students' results come from a "play with figures" rather than a conscious work with data, and the connection of prediction with results is hardly done if not purposefully planned and demanded.

As stated before, the use of MBL technology for doing school science experiments solves parts of these problems, allowing the possibility to represent and analyse real data at the same time or almost consequently to the time of the phenomena. This is also the case for VBL where, even though the phenomena is not actually taking place in the laboratory, the actual experimental data is gathered at the same time the phenomenon is happening, which allows to see the parallelism between the evolution of the phenomena and the evolution of the studied variables. Another advantage of these tools for empirical work, particularly MBL but also VBL, is the fact that the data registered is "real" data in the sense of data measured from a real phenomenon while it takes place, and not perfect data gathered from a simulation (that is, from a theoretical or numerical construct). This real data is measured according to the accuracy of the sensors or recording system used, and as a consequence, it can have more or less precision. In this sense, the certain messiness and limited accuracy that is always inherent to any real measurement of real phenomena is captured, which is very important for an appropriate differentiation between real phenomena (what happens), empirical measurement (what can be captured from what happens with the equipment at hand) and theoretical models (the theoretical modelling of what happens).

Despite these advantages of both tools, MBL and VBL are not identically interesting in this phase of a laboratory work inquiry cycle. One point to emphasise the importance of MBL for an ICT-enhanced laboratory work is the fact that the use of MBL can provide a situation very close to authentic scientific activity in real labs. Even though in real science both the phenomena, experimental design, equipment and analysis techniques are more sophisticated than in a MBL school laboratory, the sort of activities to be done are analogous, which gives more authenticity to the school situation. It is also the case that MBL have an enormous range of physical, chemical or biological phenomena to explore, whereas VBL can only deal with motion phenomena. On the other hand, with VBL one can analyse phenomena very difficult to be reproduced in the school setting, such as the fall of an object in the moon or the terminal velocity achieved by a sky diver when falling, or even the real movement of the students such as skating or biking, which can enhance interest.

Finally, our inquiry cycle includes a phase for restructuring or synthesising the knowledge being learnt along the laboratory activity. This phase can also be facilitated and supported with the use of one ICT for representing and organising knowledge. The advantages already mentioned for such tools have to be particularly stressed in the case of laboratory work and inquiry, which quite often have been criticised as a-theoretical teaching and learning activities or activities where only procedural knowledge is acquired. In an inquiry-oriented learning that pursues learning of scientific content, it is crucially important to link laboratory work with the work on scientific models or concepts, but this needs to be done by the students with teacher guidance. In this sense, restructuring what has been learnt from the studied phenomena at the empirical level with its scientific interpretation is a necessary phase that we propose to include here. The use of ICT tools for this purpose has many possibilities and facilitates these tasks. For instance, students can use concept mapping software for doing concept maps in cooperation by networking, making changes quickly and easily so that the map represents their thinking without the usual spatial or graphical restrictions.

Of course, there are other possibilities to include ICTs in a laboratory work inquiry cycle apart from the ones suggested. An example would be to include modelling software for predicting empirical results based on own mental models and later developing a conceptual model of the phenomena studied. However, we consider that the use of the ICT tools mentioned in the particular phases of a laboratory work inquiry cycle described promote the use of the potential of these tools to solve inadequate learning situations (e.g. lack of contextualisation, poor data gathering, disconnection between phenomena and results, no authenticity of the situation, no explicit connection with the concepts or models to be learnt, etc.), which are common in traditional laboratory work. Despite many of these problems can be addressed with traditional equipment, others are substantially facilitated with the introduction of ICTs in the school laboratory work.

A practical case of the use of the laboratory work inquiry cycle using some ICTs

A particular example of the integration of the laboratory work inquiry cycle of Figure 1 with some of the ICT tools mentioned to teach science is explained below. This example comes from an activity sequence for laboratory work designed locally within the project REVIR (Reality-Virtuality)[1]. This project is intended to bridge the school-university gap in science, bringing

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[1] The REVIR project is an initiative of the research centre CRECIM (Centre for Research in Science and Mathematics Education) of the Universitat Autònoma de Barcelona

Catalan secondary school students aged 13-17 and their science teachers to university-based ICT-enhanced laboratories. In REVIR a series of 4 hours-long ICT-based science laboratory sessions are designed, all using a variety of ICTs, with the purpose of addressing some topics of the official curriculum. Participating students spend a complete morning working in small with specific research-based activity sequences for each topic. These sequences have been developed and evaluated by science education researchers. The material that is provided to the students in each session consists of an activity sequence that follows the learning cycle for school laboratory work within the inquiry-oriented approach previously described, and incorporates the most appropriate ICTs for the proposed activity.

One of the activity sequences designed within this project deals with the topics of kinematics and dynamics posing the problem of road safety as the context for the whole laboratory work session. The question posed at the beginning of the session is: “What will determine that the safe stopping distance between two cars is shorter or longer?” Therefore, this laboratory session consists of an analysis of the variables affecting the stopping distance between two cars. The activity sequence is divided in two parts. The first one is addressed to the analysis of the dependence of the safe stopping distance with car speed and uses MBL technology for the empirical work. The second one is addressed to the analysis of the dependence of the safe stopping distance with reaction time by means of a simulation. The work done along this activity sequence is structured according to the inquiry-oriented learning cycle for laboratory work of Figure 1.

In the first part of the activity sequence, students:

1. Explore and discuss the problem, expressing their own ideas about the topic.
2. Are explained the experimental setup they are going to use along the session: a trolley circulating along a rail, which speeds up after being impelled by a rubber band and slows down because of a hanging object that acts as a counterweight - apart from the friction force (See Figure 2)
3. Get familiar with the experimental setup and discuss how to explain why the trolley starts moving and why it finally stops.
4. Predict the graph that represents the position of the trolley versus time.
5. Get the equipment (distance sensor connected to the computer by means of an interface, measuring the position of the moving trolley) ready to measure[2].
6. Collect the data and compare the graph obtained from experimental data with the predicted one.
7. Adjust a mathematical function to the experimental data and obtain the equation of motion provided by the software.
8. Relate experimental results to the theoretical model (motion equation for constant acceleration) to analyze the meaning and value of each of the parameters of the motion equation (initial position, initial velocity and acceleration).
9. Derive the theoretical relationship between stopping distance of the trolley and initial velocity.
10. Apply the previous results to the real example of road safety, explaining the dependence of the braking distance between cars in a road with the speed of cars.

In the second section of this laboratory session, students use a computer simulation to analyze velocity-time and position-time graphs that represent a new situation: a car that is circulating at a constant speed needs to slow down because the car in front of it is slowing down. Students can change the initial velocity of the car they control and decide when to start slowing down depending on the other car. They are expected to analyze the different graphs in order to measure their reaction time and to relate what is happening at each moment in the dynamic images (car crash, one car stopping before than the other, etc) to what is happening in the graphs (e.g. lines crossing).

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[2] To avoid spending time in technical details, instead of in the scientific discussion, students are given a document that contains some quick guidelines for configuring the software.

Summary and concluding remarks

In this paper we have discussed the important role that ICTs can play in the science laboratory work, in particular within an inquiry-oriented approach to learning, when purposefully selected and used. Our argument here, in agreement with the previous literature in the field, is that the learning potential envisaged for these tools depends on the particular characteristics of the ICTs used, but also on using them within a particular learning approach, in a particular setting, with a particular aim and in a particular sequence. In this sense, we have clarified the sort of learning possible with each of these tools and we have offered a possible model or sequence for their use in laboratory work following an inquiry-based learning cycle. An example of how this inquiry cycle can be use for the teaching and learning of a particular science topic, such as stopping distance in kinematics, has also been provided.

Our aim when discussing the most common ICTs used for teaching and learning science, proposing a way of sequencing and integrating them in an harmonious manner, is twofold. First, we would like that teachers, science education curriculum designers and policymakers realise the fact that the first step when thinking of introducing an ICT in the classroom is to wonder what is the learning potential of this tool. That is, to answer the question what can be learnt with it that it would be more difficult to be learned without it. Second, we would like them to answer this question not for a general teaching and learning situation and moment, but for a particular one, such as an inquiry orientation to learning and laboratory work (the exploration or data gathering phase within it). This is crucially important because, as described, inadequate use of these tools in science teaching does not only result in a decrease of the learning potential of those tools, but on wrong epistemologies and lack of authenticity signalling the activity. While this is problematic within the traditional classroom, it is actually a countersense within the inquiry-oriented view of teaching and learning: it denies the very essence of this framework, which aims for bringing authenticity and knowledge about science to the classroom. In this sense, we claim for more reflections and research results discussing and analysing the efficiency of particular uses of ICTs in science education, understanding by uses the characterisation of what, how and for what of ICTs for different learning environments. The results of this effort could be the elaboration of a set of strategies and models, such as the cycle proposed here, useful for guiding teaching and learning that really benefits from the potential that ICTs can bring to the field of science education.

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References

Beichner, R. J. (1990). The effect of simultaneous motion presentation and graph generation in a kinematic lab. Presented in the *Annual meeting of the National Association for Research in Science Teaching*, Atlanta.

Beichner, R. & Abbott, D. (1999). Video-Based Labs for Introductory Physics Courses. *Journal of College Science Teaching*, 29 (2), 101-105.

Brasell, H. (1987). The effects of real-time laboratory graphing on learning graphic representations of distance and velocity. *Journal of Research in Science Teaching*, 24 (4), 385-395.

Chinn, C. A. & Malhotra, B. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education, 86* (2), 175-218.

Clement, J. (2000). Model based learning as a key research area for science education. *International Journal of Science Education*, Vol. 22 (9), pp. 1041-1053.

Cox, M. J., & Abbott, C. (2004). *ICT and attainment: A review of the research literature*, Coventry and London, British Educational Communications and Technology Agency/Department for Education and Skills.

Cox, M. J., & Marshall, G. (2007). Effects of ICT: Do we know what we should know? *Education and Information Technologies*, 12, 59-70.

Evagorou, M., Korfiatis K., Nicolaou, C. & Constantinou C. (2009). An investigation of the potential of interactive simulations for developing system thinking skills in elementary school: a case study with fifth-graders and sixth-graders. International Journal of Science Education, 31, 655–74.

Fernández, C., Oro, J. & Pintó, R. (1996). Profile evolution in the interpretation of kinematics graphs using MBL technology. In *Proceedings of GIREP International Conference*. Ljubljana, Eslovenia.

Feurzeig, W. & Roberts, N. (1999). *Modeling and Simulation in Science and Mathematics Education*. Springer-Verlag New York, Inc.

Finlayson, H. & Rogers, L. (2003). Does ICT in science really work in the classroom? Part 1: The individual teacher experience. *School Science Review*.

Friedler, Y., Nachmias, R. & Linn, M. C. (1990). Learning scientific reasoning skills in Microcomputer Based Laboratories. *Journal of Research in Science Teaching*, 27 (2), 173-191.

Gilbert, J. & Boulter, C. (1998). Learning Science through Models and Modelling. *International Handbook of Science Education*. In: B. J. Fraser and K. G. Tobin, Kluwer Academic Publishers. Vol. 1, 53-66.

Glynn, S. & Duit, R. (1995). *Learning Science in the Schools: Research Reforming Practice*. Lawrence Erlbaum Associates, Publishers. New Jersey.

Halkia, Kr. & Theodoridis M. (2002). The use of pictures in science textbooks: a taxonomy and an evaluation of pictures. *Themes in Education, 3*(1), 79–95.

Hennessy, S., Deaney, R. & Ruthven, K. (2003). Pedagogic Strategies for Using ICT to Support Subject Teaching and Learning: An Analysis Across 15 Case Studies. Faculty of Education, University of Cambridge, Research Report 03/1.

Jonassen, D. H. (2006). *Modeling with technology: Mindtools for conceptual change*. Columbus, OH: Merrill/Prentice-Hall.

Kress, G. & van Leeuwen, T. (1996). Reading Images: The Grammar of Visual Design. Routledge.

Lawrence, I. (2002). A Modelling tool for expressing some thoughts in the Sciences. *Educational Technology*, Vol. 1. Proceedings ICTE, Formatex. Badajoz, 52-57.

Lijnse, P. (2006). Models of/for teaching modeling. *Proceedings of the GIREP Conference on Modelling in Physics and in Physics Education*. University of Amsterdam.

McDermott, L. C., Rosenquist, M. L. & Van Zee, E. H. (1987). Student difficulties in connecting graphs and physics: Examples from kinematics. *American Journal of Physics*, 55 (6), 503-213.

Mokros, J. R. & Tinker, R. F. (1987). The impact of MicroComputer Based Labs on children's ability to interpret graphs. *Journal of Research in Science Teaching*, 24 (4), 369-383.

Monaghan, J. M. & Clement, J. (1999). Use of a computer simulation to develop mental simulations for understanding relative motion concepts. *International Journal of Science Education*, 21 (9), 921-944.

Moseley, D., Higgins, S., Bramald, R., Hardman, F., Miller, J., Mroz, M., Harrison, T., Newton, D., Thompson, I., Williamson, J, Halligan, J., Bramald, S., Newton, L., Tymms, P., Henderson, B. & Stout, J. (1999). *Ways forward with ICT: Effective Pedagogy using Information and Communications Technology for Literacy and Numeracy in Primary Schools*. Newcastle: Newcastle University, Durham University and CEM Centre, Durham University.

National Research Council (*2000*). *Inquiry* and the *national science education standards*: A guide for teaching and learning. Washington, DC: National Academy

OCDE (2001). *Learning to Change: ICT in Schools*, Paris.

Osborne, J. & Hennessy, S. (2003). *Literature Review in Science Education and the Role of ICT. Promise, Problems and Future Directions*. NESTA Futurelab Series.

Osborne, J. F. & Dillon, J. (2008). *Science Education in Europe: Critical Reflections.* A report to the Nuffield Foundation. Available online at:
http://www.nuffieldfoundation.org/fileLibrary/pdf/Sci_Ed_in_Europe_Report_Final.pdf

Penner, D. E. (2000-2001). Cognition, computers and synthetic science: building knowlegde and meaning through modeling. *Review of Research in Education*, 25, 1-35.

Pintó, R., Pérez, O. & Gutiérrez, R. (1999). Implementing MBL (Microcomputer Based Laboratory) technology for the laboratory work in compulsory secondary school science classes. *STTIS Spanish National report on WP1*. Universitat Autònoma de Barcelona.

Pintó, R., Ametller, J. (2002). Students difficulties in reading images. Comparing results from four national research groups. *International Journal of Science Education* 24(3), 333-341.

Pintó, R. & Gutiérrez, R. (2004). Analysing Computer Scientific Simulations from a Didactical Point of View. *Proceedings of the GIREP Conference on Teaching and Learning Physics in new contexts*. University of Ostrava.

Pintó, R. (2009). Choosing ICT: A matter of learning about learning science. In P. Kariotoglou, A. Spyrtou & A. Zoupidis (Eds): *Proceedings of the 6th Panhellenic Conference of Science Education and ICT in Education - The multiple approached to teaching and learning about Science*. School of Education, University of Western Macedonia (Florina), 19-29.

Rocard, M., Csermely, P., Jorde, D., Lenzen, D., Walwerg-Henriksson, H. Y Hemmo, V. (2007). *Science Education Now: A Renewed Pedagogy for the Future of Europe.* European Commission. Available online at:
http://ec.europa.eu/research/science-society/document_library/pdf_06/report-rocard-onscience-education_en.pdf

Saez, M., Pintó, R. & Garcia, P. (2005). Interconnecting concepts and dealing with graphs to study motion. In R. Pintó & D. Couso (Eds), *Proceedings of the Fifth International ESERA Conference on Contributions of Research to Enhancing students' interest in Learning Science*, 1229-1232.

Sassi, E., Monroy, G. & Testa, I. (2005). Teacher training about real-time approaches: Research-based guidelines and training materials. *Science Education*, 89 (1), 28-37.

Schwartz, R. S., Lederman, N. G., & Crawford, B. A. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education*, *88*(4), 610-645.

Thornton, R. K. & Sokoloff, D. R. (1990). Learning motion concepts using real-time microcomputer-based laboratory tools. *American Journal of Physics*, 58, 858-867.

White, R. T., & Gunstone, R. F. (1992). *Probing Understanding*. Great Britain: Falmer Press.

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